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Effects of Intensive Silvicultural Treatments on Kraft Pulp Quality of Loblolly and Slash Pine

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EFFECTS OF INTENSIVE SILVICULTURAL TREATMENTS ON KRAFT PULP QUALITY OF LOBLOLLY AND SLASH PINE

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ABSTRACT

Intensive forest-management practices have been shown to greatly increase the growth rates of southern pines. A joint study was undertaken to evaluate the wood and pulp quality from fast-grown 14-year-old loblolly pine from the Piedmont and 17-year-old slash pine from the Coastal Plain. The properties were compared to 24-year-old plantation-grown controls. Three sets of chip samples, sawmill residual, top log, and whole stem, were prepared from each wood source. Two unbleached pulp grades, linerboard at kappa no. 90 and sack kraft at kappa no. 60, were prepared from each chip sample, and the pulp yields, fiber lengths, and handsheet properties were compared. A bleachable grade pulp, kappa no. 30, was also made and the pulp yields and fiber lengths measured.

Within each chip type, there was not a significant adverse effect on pulp yield from the intensive management practices for the unbleached grades. Chips from the top log samples with a high proportion of juvenile wood had significantly lower packed bulk density and lower pulp yields than pulps from the sawmill residual chips. For the unbleached grades, there was no overall significant negative impact on handsheet strength from the intensive management practices. Pulps from the top wood chips had higher burst, tensile, and compression strength but lower tear.

For the bleachable grade pulps, there was some loss in pulp yield for the for the accelerated-growth loblolly pine pulps while the accelerated-growth slash pine exhibited no loss in pulp yield compared to the control.

INTRODUCTION

The pulp and paper industry in the Southeastern U.S. is facing increased competition from imported products while paying higher stumpage fees for southern pine timber because of reduced acreage for timber production along with an increasing demand. Foresters are using more intensive management practices to increase the yield of wood fiber from a shrinking land base. These management practices include competition control, fertilization, and shorter rotations to accelerate growth. The typical loblolly pine plantation in the Southeastern U.S. produces 4.9 to 8.0 m^3/hectare/year. Research has shown that with intensive management practices and genetically improved stock, growth rates can be increased 15 to 25 m^3/hectare/year. These growth rates compare well with the fastest growing loblolly pine anywhere in the world.[1]

Accelerated growth and shorter rotations will produce a higher percentage of juvenile wood in the harvested timber which can have a major impact on pulping and papermaking operations. Juvenile wood of southern pines has a lower specific gravity, higher moisture content, less cellulose, and more hemicellulose and lignin.[2] This can result in lower packing densities in digesters and reduced pulping yield.[3,4] Fibers from juvenile wood are shorter and have thinner cell walls.[5] These juvenile fibers have some benefits with increased sheet bonding and higher tensile and burst properties but lower tear strength.[6]

A joint study by the University of Georgia, the Institute of Paper Science and Technology, the USDA Forest Service, and the Rayonier Specialty Pulp Products Company along with collaboration from industry partners was undertaken to evaluate the wood and pulp quality from fast-grown loblolly and slash pine. The effects of planting density [988, 1,483, 1,977 TPH (trees/hectare)] and herbaceous competition control of 14-year-old loblolly pine in the Piedmont and herbaceous competition control and fertilization of 17-year-old slash pine in the Coastal Plain on wood properties, pulp yield, and paper properties were examined. The properties of the young trees were compared to that of a 24-year-old loblolly plantation in the Piedmont and a 24-year-old slash pine plantation in the Coastal Plain.

WOOD GROWTH AND CHIP QUALITY

The effects of the management practices on the growth and wood properties have been reported previously.[7] Wood samples were quantified as to annual growth increments, percent latewood per growth ring, and the proportion of juvenile wood. A summary of the wood growth is shown in Table I. Controlling competing vegetation dramatically accelerated the growth of both the 14-year-old loblolly pine and 17-year-old slash pine. The mean annual growth increment (MAI) of the 14-year-old loblolly pine was 61 to 71% higher than that of a 24-year-old control. For the 17-year-old slash pine, the MAI increased 106-125% compared to a 24-year-old control.

Table I. Wood Growth by Treatment for Loblolly and Slash Pine Plantations

Treatment	Trees per Hectare No.	DBH cm.	Pulpwood Stem Weight MTN/Ha	Mean Annual Increment m^3/Ha
Loblolly 988 TPH, age 14	976	23.1	269	18.5
Loblolly 1,483 TPH, age 14	1,322	20.1	280	19.2
Loblolly 1,977 TPH, age 14	1,730	18.3	298	20.2
Loblolly control, age 24	509	28.2	303	11.8
Slash herbicide, age 17	1,139	17.8	198	10.1
Slash herbicide & fertilizer, age 17	1,189	18.3	215	11.0
Slash control, age 24	927	16.8	137	4.9

The proportion of juvenile wood in the saw log stem volume is shown in Figure 1. The loblolly and slash pine controls have 10 to 25% less juvenile wood than the accelerated-growth trees. The Coastal Plain slash pine had significantly less juvenile wood than the Piedmont loblolly pine but this is due more to differences in summer rainfall and length of growing season than a species difference.[8]

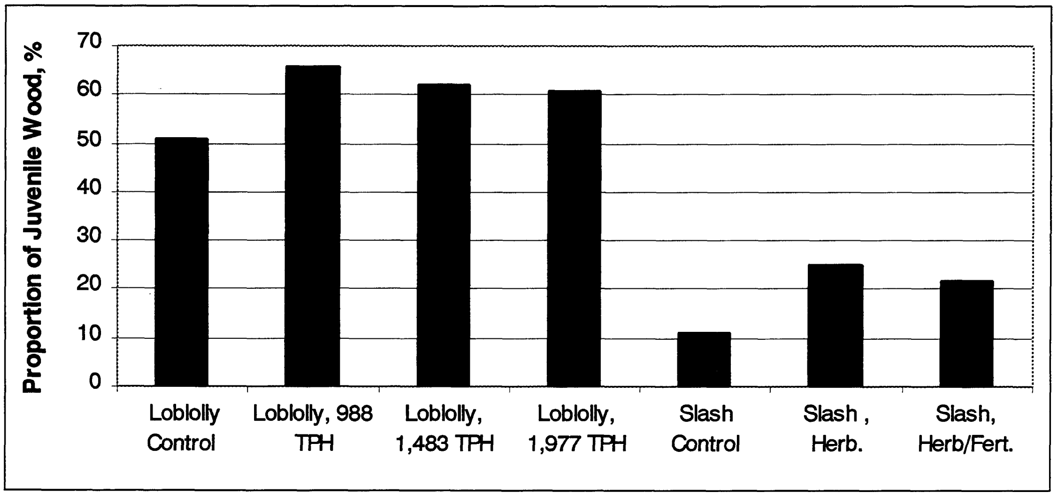

Figure 1. Proportion of Saw Log Stem Wood Classified as Juvenile Wood

Three types of chips were prepared from selected trees from the growth plots. These were sawmill residue chips (28 cm to 15 cm top) , top log chips (15 cm to 5 cm top), and whole stem chips. The grade, yield, and strength of the lumber produced from the study trees was also determined and will be reported separately.[9] The packed bulk density of the chips and the wood disk specific gravity are shown in Table II. The top log chips are 12-20% lower in packed bulk density, and the whole stem chips are 7-15% lower than the sawmill chips. Within each chip type, however, samples from the intensively managed stands had either higher or comparable bulk densities.

For the loblolly samples, there was little difference in the specific gravity among the treatments within each chip type and between the sawmill and whole stem samples. The specific gravity of the top wood samples was 9-12% less than the sawmill residual samples. The specific gravity of the slash pine samples from the managed stands was 5-8% lower than the control, while the top wood had a specific gravity 12-15% lower than the sawmill samples.

Table II. Packed Bulk Density (kg/m^3) and Specific Gravity of Chip Samples

Chips	Sawmill Residual		Top Log		Whole Stem	
Treatment	Packed Bulk Density	Wood Disk Specific Gravity	Packed Bulk Density	Wood Disk Specific Gravity	Packed Bulk Density	Wood Disk Specific Gravity
Loblolly 988 TPH	162.6	0.43	133.0	0.38	146.4	0.42
Loblolly 1,483 TPH	162.1	0.43	128.6	0.39	141.0	0.42
Loblolly 1,977 TPH	155.9	0.42	137.4	0.38	151.8	0.43
Loblolly control	153.9	0.44	120.8	0.39	131.4	0.41
Slash herbicide	193.6	0.53	160.2	0.46	177.6	0.52
Slash herbicide & fertilizer	189.3	0.53	156.6	0.45	175.3	0.52
Slash control	197.2	0.56	156.2	0.49	179.2	0.55

KRAFT PULPING - UNBLEACHED GRADES

Kraft pulping of the chip samples for the unbleached grades was done at the IPST laboratory. Two grades were targeted, a sack kraft grade at kappa no. 60 and a linerboard grade at kappa no. 90. Actual batch pulping experiments resulted in 150 pulps covering a range of kappa nos. from 37 to 124. Fewer cooks were completed for the whole stem chips due to project timing.

Pulping Yield

The total yield and kappa no. results from all the cooks were subjected to multiple regression analysis. The predicted total yields at each of the two target kappa nos. of 60 and 90 are shown in Table III. The young loblolly samples had the same or higher yields for the sawmill and top log chips compared to the control. The loblolly 988 and 1,977 TPH whole stem chips appeared to result in lower yields, but this is based on only a few cooks that were completed for these samples. The slash pine herbicide sample had a somewhat lower yield than the slash control. The top log samples resulted in lower yields overall because of the higher proportion of juvenile wood. In general, there does not appear to be a significant yield penalty for the accelerated-growth younger trees compared to the controls within each chip type.

Table III. Predicted Total Yields for Unbleached Grades

Chips	Sawmill Residual		Top Log		Whole Stem	
Kappa No.	60	90	60	90	60	90
Loblolly 988 TPH	49.8%	53.4%	47.8%	51.4%	47.8%	51.5%
Loblolly 1,483 TPH	49.8%	53.4%	47.8%	51.4%	49.8%	53.4%
Loblolly 1,977 TPH	49.8%	53.4%	48.8%	52.5%	46.7%	50.3%
Loblolly control	49.8%	53.4%	47.8%	51.4%	49.8%	53.4%
Slash herbicide	49.8%	53.4%	47.8%	51.4%	49.8%	53.4%
Slash herbicide & fertilizer	51.2%	54.9%	47.8%	51.4%	51.6%	55.2%
Slash control	50.8%	54.9%	48.8%	52.9%	50.8%	54.9%

The whole stem pulps at the higher kappa nos. had considerably more rejects after refining and screening, typically 8-15% of the dry chip charge. The chip size of the whole stem samples was more variable than the other chip samples with a number of larger chips. The sawmill and top log chips had screen rejects of 1-5% at the higher kappa nos.

Unbleached Kraft Pulp Quality

Pulp samples at the target kappa nos. of 60±3 and 90±4 were analyzed for fiber length distribution and handsheet strength properties.

Fiber Length The length-weighted average fiber lengths are shown in Figure 2 for the loblolly pine samples and in Figure 3 for the slash pine samples. The fiber length is somewhat lower for the kappa 60 pulps than the kappa 90 pulps due to the greater degree of delignification. For the loblolly samples, the 988 TPH sample has the shortest fiber length while the 1,977 TPH sample is nearly equal to or greater than the control. There is not a significant difference among treatments for the slash pine samples within a given chip type. For both the loblolly and slash pine, the top log samples have average fiber lengths that are 12-20% shorter than the sawmill samples while the whole tree samples that were completed are similar to or somewhat longer than the top log samples.

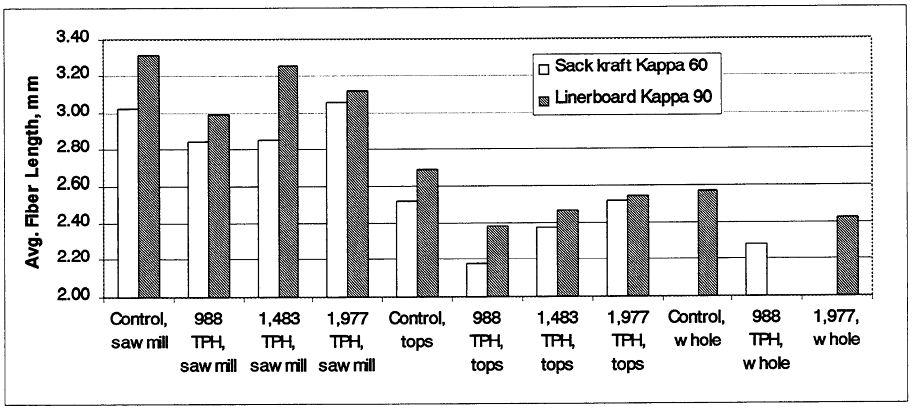

Figure 2. Length-Weighted Average Fiber Lengths for Loblolly Pine Unbleached Grades

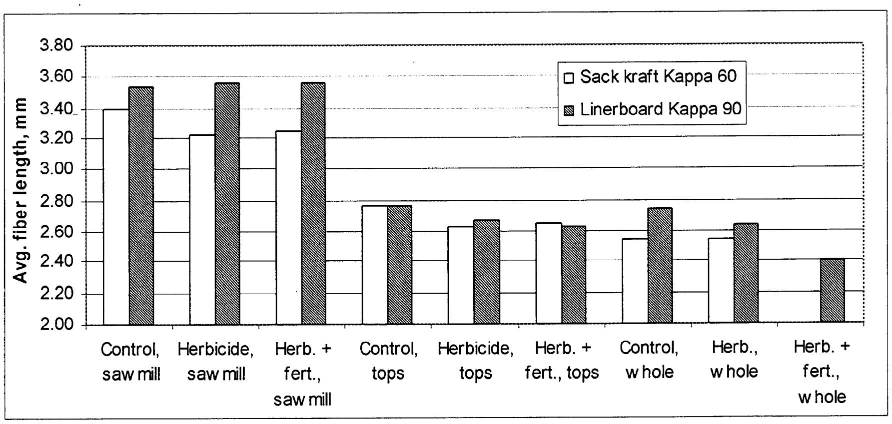

Figure 3. Length-Weighted Average Fiber Lengths for Slash Pine Unbleached Grades

Handsheet Properties - Linerboard Grade Handsheet strength properties were measured after refining in a Valley beater. Handsheets were made at a basis weight of 205 o.d. g/m^2 for the linerboard grade pulps. The handsheet properties were interpolated to a freeness (CSF) of 500 ml for comparison and are shown in Table IV.

The top wood samples for the loblolly chip sources had a sheet density 12-20% higher than the sawmill chip samples and 9-11% higher sheet density for the slash pine due to the high percentage of thinner-walled juvenile fibers. This higher sheet density translates into increased bonding and correspondingly higher burst, tensile, and STFI compression strength.

For the loblolly pine samples, there is no reduction in STFI compression, burst, or tensile strength among the treatments within each chip type. Pulps from the managed stands compare well to the respective controls. There is some reduction in specific modulus compared to the control within each chip type. The whole stem control pulp had a lower strength than the other samples, but the 1,977 TPH whole stem pulp had handsheet strengths similar to the sawmill pulps.

For the slash pine, there were no significant differences among the treatments for STFI compression, burst strength, or specific modulus but pulps from the treated stands had a lower tensile strength. Among the top wood samples, the treated samples had higher strength compared to the control. Pulps from the whole stem chips had strength results comparable to the pulps from the sawmill chips. Similar to the loblolly pine samples, the top wood pulps had overall higher strength than pulps from the sawmill or whole stem samples.

Table IV. Strength Results at 500 CSF for Linerboard Grade Pulps

Treatment	Sheet Density	STFI Index	Burst Index	Tensile Index	TEA Index	Specific Modulus	% Stretch
Loblolly 988 TPH sawmill	725	30.2	5.67	71.9	1195	6555	2.78
Loblolly 1,483 TPH sawmill	704	30.3	5.38	71.5	1440	6165	2.98
Loblolly 1,977 TPH sawmill	670	29.3	5.40	70.1	1415	5970	2.96
Loblolly control sawmill	690	30.1	5.35	68.0	1265	6685	2.61
Loblolly 988 TPH top log	814	33.9	6.50	86.6	1860	7040	3.16
Loblolly 1,483 TPH top log	786	35.6	6.56	75.0	1710	6710	3.23
Loblolly 1,977 TPH top log	788	33.0	6.54	82.7	1610	7380	2.84
Loblolly control top log	808	35.2	6.65	74.7	1345	7455	2.57
Loblolly1,977 TPH, whole stem	784	30.0	5.85	69.3	2125	5975	4.19
Loblolly control, whole stem	769	27.3	5.08	59.5	1970	5995	4.15
Slash herb., sawmill	637	26.1	4.68	46.0	1800	5600	4.15
Slash herb. & fert., sawmill	645	27.2	5.13	49.6	1280	5260	3.22
Slash control, sawmill	618	26.4	4.82	59.7	955	5920	2.54
Slash herb., tops	700	29.3	5.44	70.8	1485	6445	2.98
Slash herb. & fert., tops	717	30.3	5.53	72.5	1310	7010	2.65
Slash control, tops	675	26.8	5.17	61.0	1030	6470	2.43
Slash herb., whole stem	670	25.8	4.65	58.5	1500	5395	3.55
Slash herb. & fert., whole stem	715	26.7	5.20	54.2	1960	5550	4.35
Slash control, whole stem	687	27.2	4.96	55.5	1570	5410	3.65

Handsheet Properties – Sack kraft grade The handsheet properties at a basis weight of 98 o.d. g/m^2 for the sack kraft grades interpolated to a freeness of 500 CSF are shown in Table V. Testing of the whole stem samples was incomplete, and results are shown only for the slash control and slash herbicide samples.

Sack kraft pulps from the loblolly 988 and 1,483 TPH sawmill chips had lower tear and tensile strengths compared to the control, while pulps from the 1,977 TPH sawmill chips had higher tensile and burst but slightly lower tear strength. For the top wood pulps, the 988 TPH sample had lower tear, tensile, and burst strength, while the 1,483 and 1,977 TPH samples had higher tensile and burst but lower tear compared to the top wood control.

Similar to the linerboard pulps, the top wood samples produced sheets with increased bonding resulting in higher sheet density, specific modulus, tensile, and burst strength compared to pulps from the sawmill chips. However, the shorter fiber length of the top wood samples results in a lower tear strength compared to the sawmill samples.

For the slash pine samples, pulps from the treated sawmill chips had lower tensile strength but similar tear and burst strength compared to the control. For pulps from the top wood chips, the herbicide and fertilizer treatment sample had higher tensile and burst strength but similar tear strength compared to the control. Pulps from the whole stem chip samples that were completed had either somewhat lower or similar strength compared to pulps from the sawmill chips.

Table V. Strength Results at 500 CSF for Sack Kraft Grades

Treatment	Sheet Density	Tear Index	Burst Index	Tensile Index	TEA Index	Specific Modulus	% Stretch
Loblolly 988 TPH sawmill	683	14.6	7.36	87.4	1980	7150	3.12
Loblolly 1,483 TPH sawmill	674	14.5	7.50	84.8	1605	7276	3.02
Loblolly 1,977 TPH sawmill	670	15.5	8.10	96.2	2000	7550	3.20
Loblolly control sawmill	660	16.9	7.36	90.0	1820	7200	3.10
Loblolly 988 TPH top log	739	12.4	7.68	94.4	1710	7780	2.88
Loblolly 1,483 TPH top log	798	12.5	8.47	109.5	2230	9200	3.02
Loblolly 1,977 TPH top log	752	13.5	8.20	105.0	2005	8690	2.94
Loblolly control top log	745	14.3	7.81	98.8	2000	8010	3.04
Slash herb., sawmill	616	20.8	6.22	68.3	1420	6740	3.02
Slash herb. & fert., sawmill	618	20.0	6.03	65.5	1400	6320	3.09
Slash control, sawmill	581	21.4	6.20	78.6	1565	7000	3.01
Slash herb., top log	636	17.8	6.25	83.5	1500	7630	2.71
Slash herb. & fert., top log	670	17.6	7.03	88.5	1670	7570	2.85
Slash control, top log	639	18.1	6.35	81.2	1378	7580	2.54
Slash control, whole stem	627	19.1	5.90	70.7	1540	6140	3.19
Slash herb., whole stem	630	19.9	5.80	73.7	1650	6690	3.25

KRAFT PULPING - BLEACHABLE GRADE

Bleachable grade pulps from the same chip sources were prepared and tested by the Rayonier Specialty Pulp Products Company, Jesup, GA. Different measurements and techniques were used, so the results may not be directly comparable to the unbleached grade results. For these cooks, the degree of digester delignification was measured by a K (permanganate) no. test.

Pulp Yield

The total yield as a function of the K no. from duplicate cooks of each chip sample was subjected to multiple regression analysis. From this analysis, the total yield at a K no. of 20.5 (kappa no. 30) was calculated and the results are shown in Table VI. For the loblolly pine samples, the 988 TPH samples have 4-5% lower yields than the respective controls while the other samples from the managed stands have slightly lower or similar yields. For the whole stem chips, the total yield from the managed stands is 2.5-5% lower than the control. For the slash pine pulps, the total yield from the managed stand chip samples is similar to or slightly higher than the control. The top log samples had 1.5-8% lower yields than the sawmill samples.

Table VI. Predicted Total Yield for Bleachable Grade Pulps at K No. 20.5 (Kappa no. 30)

Treatment	Sawmill Chips	Top Log Chips	Whole Stem Chips
Loblolly control	48.6%	44.8%	46.8%
Loblolly 988 TPH	45.6%	42.7%	44.8%
Loblolly 1,473 TPH	46.3%	45.6%	45.6%
Loblolly 1,977 TPH	46.6%	45.1%	44.4%
Slash control	47.6%	45.6%	45.8%
Slash herbicide	48.6%	45.6%	47.7%
Slash herbicide & fertilizer	48.1%	45.2%	47.2%

Fiber Length

The length-weighted average fiber lengths are shown in Figure 4 for the loblolly pine samples and in Figure 5 for the slash pine samples. There was some variation among the treatments within each chip type for the loblolly pine. The 988 TPH sample had the shortest fiber length, while the 1,977 TPH sample had a longer fiber length than the respective control for the top log and whole stem samples. The fiber lengths of the top log samples were significantly shorter, by 18-28%, than the sawmill samples. Fiber lengths from the whole stem pulps were generally between the corresponding top log and sawmill sample fiber lengths.

The average fiber length for the slash pine samples did not show any difference between the treated samples and the control within each chip type. The average fiber lengths of the top wood samples were 22-26% shorter than the corresponding sawmill samples. The average fiber lengths for pulps from the whole stem chips were similar to or somewhat shorter than pulps from the top log samples.

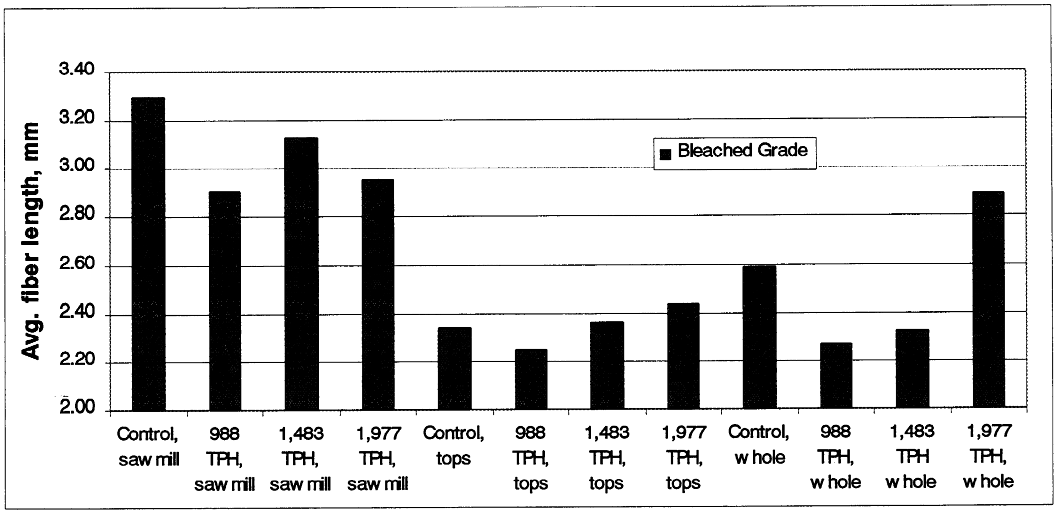

Figure 4. Length-Weighted Average Fiber Length for Loblolly Pine Bleached Grade

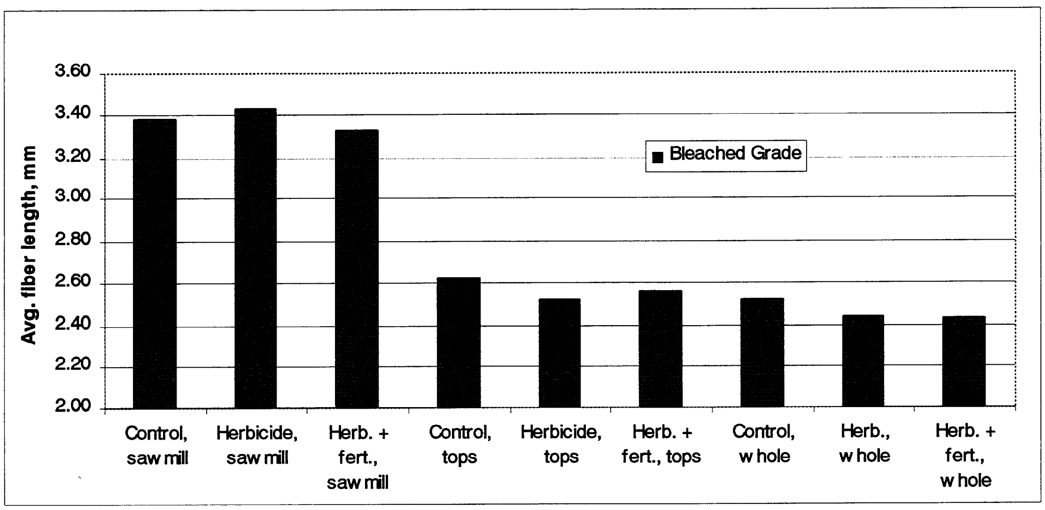

Figure 5. Length-Weighted Average Fiber Length for Slash Pine Bleached Grade

EXPERIMENTAL

Materials

The selection and processing of the tree samples has been described previously.[7] Disk wood specific gravity was calculated based on oven dry weight and green volume. Individual disk values where weighted in proportion to disk basal area to obtain a weighted stem value.

A ChipClass™ Classifier, with the following tray series, was used to determine the size distribution for all the chips: 45-mm round hole, 8-mm bar, 7-mm round hole, 3-mm round hole, and the pan. Bark, knots, and slivers (thin pieces of wood longer than 7.6 cm) were removed before chip charges were made. Moisture content was determined, and all chip charges were made on an oven-dried basis, double bagged to prevent moisture loss, and frozen until used. Chip charges for sawmill residual chips were made up in proportion to the percentages in each size category (minus bark, knots, and slivers).

Top log chips were processed from short pieces of wood 31 cm (12 inches) long, and whole log chips from disks only 7.6 cm wide (3 inches). The result of chipping this type of wood resulted in a disproportionate amount of pins, fines, and oversized chunks, similar to what is produced from lily pads. An initial analysis showed that only about 70 percent of the material was usable for pulping. Therefore, the chip furnishes were screened with a laboratory-sized gyratory chip screen that had a 3.9 x 3.9 cm (1.5 x 1.5 in) square mesh top screen and an oval, punch-plate bottom screen 1.6 x 0.8 cm (5/8 x 5/16 inch). The remaining chips were used to make up chip charges.

The packed bulk density was measured in a volumetric container after settling with an air-driven shaker.

Unbleached Grades

The sack kraft and linerboard grade pulps were prepared at the Institute of Paper Science and Technology, Atlanta, GA. Pulping was done in either a 6-L or 10-L batch digester with liquor circulation and external electric heating. The cooking conditions were 17.5% AA, 30% sulfidity, 4:1 liquor:wood ratio, 170°C cooking temperature, and time to temperature of 60 minutes. The time at temperature was varied to reach the target kappa no. For most of the chip samples, duplicate cooks were done at the target kappa nos. The cooked chips were refined in a 12" Sprout-Waldron refiner at a clearance of 0.010". The refined pulp was screened on a Sprout-Waldron flat screen with 0.006" slots. The screen rejects and accepts were collected and the dry weight determined for calculation of the total and screened yields. The kappa no. was measured on the screen accept pulp.

Fiber length was determined by a Kajaani FS-100 instrument. Pulps for testing were refined in a Valley beater to four freeness levels. Handsheets for the linerboard grade pulps were made at a basis weight of 205 o.d. g/m^2, and the density, burst strength, STFI compression strength, tensile strength, tensile energy absorption, modulus, and stretch were measured. Handsheets for the sack kraft grade were made at a basis weight of 98 o.d.g/m^2, and the density, tear strength, burst strength, tensile strength, tensile energy absorption, modulus, and stretch were measured.

Bleachable Grade

The bleachable grade pulps were prepared at Rayonier Research Center, Jesup, GA. Pulping was done in a 20-L batch digester with liquor circulation and indirect heating. The cooking conditions were 19% AA, 30% sulfidity, 4:1 liquor:wood ratio, 170°C cooking temperature, time to temperature of 90 minutes, and time at temperature of 90 minutes. Duplicate cooks were done for each chip sample. The chips were defibered, washed, and screened on a flat screen with 0.008" slots. The screen rejects and accepts were collected and the dry weight determined for calculation of the total and screened yields. The K no. was measured on the screen accept pulp. Duplicate cooks were blended together and the average fiber length determined by an OpTest Fiber Analyzer.

CONCLUSIONS

Increased planting density and competition control has been shown to greatly accelerate the growth rates of plantation-grown loblolly pine such that the total growth after 14 years is nearly equal to that of a natural 24-year-old stand. Intensive fertilizer and herbicide treatments of a slash pine plantation resulted in total wood production that was 50% greater after 17 years than a 24-year-old natural stand. The accelerated-growth trees had 12-20% more juvenile wood.

For unbleached grade pulps, there was not a significant adverse impact of the accelerated growth on pulp yield or handsheet strength properties within each chip type. For the bleached grade pulps, there was some loss in pulp yield from the accelerated-growth loblolly pine samples while there was no loss in pulp yield with the treated slash pine samples.

The top wood portion of each tree sample, containing essentially all juvenile wood, had a significantly lower specific gravity, fiber length, and pulp yield than the corresponding sawmill residual sample. Unbleached grade pulp from the top wood samples had higher handsheet density, modulus, tensile, burst, and STFI compression strength but significantly lower tear strength than pulps from the sawmill residual pulps. Pulps from whole stem chip samples had fiber and sheet properties that were typically between the sawmill residual and top log pulp samples.

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